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CHARGE CALCULATION FOR UNDERWATER BLAST DEMOLITION AND ITS APPLICATION

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ABSTRACT

It appears to be an effective method to demolish concrete containers or container-like structures by underwater blast. As compared with conventional blast by charge within drilled holes, underwater blast has advantages in some respects such as simplicity of work process, lower cost, lower noise, less effect of air blast wave and better control of fragments.

In this paper, equations for underwater blast charge calculation are analyzed and derived for cylindrical and rectangular structures on the basis of properties of underwater blast loading, strength and dynamic characteristics of structures, and two examples of application are given.

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CHARGE CALCULATION FOR UNDERWATER BLAST DEMOLITION AND ITS APPLICATION

It appears to be a relatively effective method to demolish concrete containers or container-like structures by underwater blast. As compared with conventional blast by charge within drilled holes, underwater blast has advantages at least in some aspects as below:

1. Simplicity of work process;
2. Lower cost;
3. Lower noise;
4. Less effect of air blast wave;
5. Better control of direction and range of scattered fragments.

Thus, since 1978, research work on underwater blast demolition for application within urban area has started by organizations of railway engineering.

I. BLAST WAVE OF WATER PRESSURE

The demolition object with peripheric faces exposed above ground and footing underground may be considered as an one degree freedom structure, and according to D'Alembert's principle, the vibration equation for this structure with damping under dynamic load may be expressed as

$$m\ddot{y}(t)+\gamma\dot{y}(t)+Ky(t)=P(t) \qquad (1)$$

if we substitute $\gamma=2\xi m\omega$ into equation (1) , we get

$$\ddot{y}(t)+2\xi\omega\dot{y}(t)+\omega^2 y(t)=\frac{1}{m}P(t) \tag{2}$$

when t>u, the solution of equation (2) is

$$y(t)=\frac{1}{m\omega}\int_0^t P(u)e^{-1/2\gamma\bar{\omega}(t-u)}\sin\bar{\omega}(t-u)du \tag{3}$$

where y(t) --- displacement of vibration;

m --- mass;

K --- stiffness factor;

γ --- damping factor;

ξ --- damping ratio;

ω --- natural circular frequency without damping,

$$\omega=\sqrt{\frac{K}{m}};$$

$\bar{\omega}$ --- natural circular frequency with damping,

$$\bar{\omega}=\frac{\omega}{\sqrt{\left(1+\frac{1}{4}\gamma^2\right)}};$$

P(t) --- dynamic load

Generally we call equation (3) as Duhamel Integral for system with damping, it may be used to calculate the response of one degree freedom system with damping under dynamic load of any type. Usually, when explosives being blasted underwater, the duration τ for blast wave of water is much less than that for air blast, the difference is about two order of magnitude. Also the charge weight needed for underwater blast is relatively small, therefore under general condition, $\tau<\frac{1}{4}T$ (T--natural period of structure). Thus the demolish action of blast wave in water to a structure may be considered as the action of im-

pulse I, as shown in Figure (1)

Since impulse I is expressed as

$$I=\int_0^{\tau} P(t)dt,\quad \tau\to 0,\quad P(t)\to\infty$$

at this time, $y(t)=\frac{I}{m\bar{\omega}}e^{-1/2\gamma\bar{\omega}t}\times\sin\bar{\omega}t$

$$y_m=\frac{I}{m\bar{\omega}}e^{-1/4\gamma\pi},\quad t_m\approx\frac{1}{4}\bar{T}$$

$$y_1=\frac{I}{m\bar{\omega}}e^{-3/4\gamma\pi},\quad t_1\approx\frac{3}{4}\bar{T}$$

$$\bar{T}=\frac{2\pi}{\bar{\omega}}$$

$$P_{eq}=Ky_m=I\bar{\omega}e^{-1/4\gamma\pi}$$

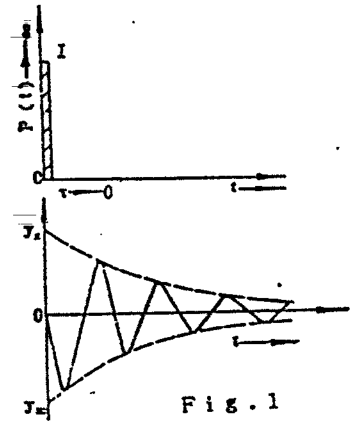

Fig.1

where P_{eq} --- equivalent static load, under the action of this load, the max. displacement of structure is the same as that under the action of blast wave impulse I.

Generally the internal damping is rather small for ordinary contruction materials, $\gamma=0.015$ for concrete, $\gamma=0.015\sim0.018$ for reinforced concrete, therefore:

$$e^{-1/4\gamma\pi}\approx 1$$

and
$$\bar{\omega}=\frac{\omega}{\sqrt{1+\frac{1}{4}\gamma^2}}\approx\omega$$

Therefore, equation (4) may be more simplified as

$$P_{eq}=I\omega \qquad \text{kg/cm}^2 \qquad (5)$$

For TNT of density $1.5g/cm^3$, when being blasted underwater, the impluse I on unit area at distance R may be calculated by

$$I=0.0588Q^{1/3}\left(\frac{Q^{1/3}}{R}\right)^{0.89} \qquad \text{kg.sec/cm}^2 \qquad (6)$$

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where Q --- charge wt., kg;

R --- distance from blast center to the loading face of structure, m.

Substitute equation (6) into equation (5), we get the equivalent static load of water pressure blast

$$P_{eq} = 0.0588Q^{1/3}\left(\frac{Q^{1/3}}{R}\right)^{0.89}\omega \tag{7}$$

II. EQUATION OF CHARGE CALCULATION FOR UNDERWATER BLAST

In the application of underwater blast demotion, usually we deal with cylindrical and rectangular structures. Thus, the equations of charge calculation for underwater blast demolition of these two types of structure shape are discussed in this paper. For shapes that are nearly rectangular or cylindrical, they may be treated as cylindrical or rectangular by some simplification of shape.

1. Thin Wall RC Cylinder

The definition for a thin wall cylinder is that $\delta/R<0.1$, where δ is the wall thickness, and R is the radius of cylinder.

The natural frequency of a cylinder is

$$\omega=\frac{c}{R} \tag{8}$$

where c --- velocity of sound wave within concrete, m/sec, see Table 1;

R --- radius of cylinder, m.

Table 1 Values of R_t and c for Concrete

Mark No. of Concrete	100	150	200	250	300	350	400
R_t (kg/cm²)	8.0	10.5	13.0	15.5	17.5	21.5	24.5
c (m/sec)	2760	3060	3260	3420	3500	3585	3670
$K_d R_t / 0.0588c$	0.069	0.082	0.095	0.108	0.119	0.142	0.159

For a thin wall concrete cylinder under uniform internal pressure, if the charge center is placed at the center of cylinder, then the stress of cylinder wall is

$$\sigma = \frac{P_{eq} R}{\delta}$$

When this stress exceeds the strength of concrete, failure of the structure will occur. But for blast demolition, this stress will exceed the strenth of concrete extremely, then a factor K_b is introduced, which is called the factor of damage degree for the structure after blast, thus we get:

$$\sigma = \frac{P_{eq} R}{\delta} \geqslant K_b K_d R_t \qquad (9)$$

Substitute equations (7) and (8) into (9), we get the equation for charge calculation of a thin wall concrete cylinder.

$$Q_{cyl} = \left(\frac{K_b K_d R_t}{0.0588 \times c}\right)^{1.59} \delta^{1.59} R^{1.41}, \quad \text{kg} \qquad (10)$$

where K_d --- factor of increased dynamic strength for concrete, $K_d = 1.4$;

R_t --- static tensile strength of concrete, kg/cm²,

see Table 1;

δ --- wall thickness of cylinder, m;

K_b --- factor of damage degree for structure after blast

(1) Correction Factor for Reinforcement

Usually we have reinforcement in the wall of concrete cylinder, we may approximately treat this problem by changing the area of steel to area of concrete according to static tensile strength ratio of steel and concrete, then evaluate the factor K_s for reinforcement. The charge value from equation (10) should be multiplied by K_s to increase its value.

$$Q_c = K_s Q_{cyl} \tag{11}$$

where $$K_s = 1 + \frac{K_{ds} R_s (\Sigma A_s)}{K_d R_t b\delta} \tag{11a}$$

and b --- unit width, $b=1m$;

K_{ds} --- factor of increased dynamic strength for steel, $K_{ds}=1.35$ for mild steel;

R_s --- static yield strength of steel, here we use $R_s=$ 3800 kg/cm^2;

$\sum A_s$ --- the total area of circumferential steel along unit length b of longitudinal section, m^2

(2) Factor of Damage Degree, K_d

As for the requirement of blast demolition, the damage degree of structure exceeds by far that at plastic deformation stage, and may be expressed by factor of damage degree K_b.

K_b may be divided as three damage levels, and the value of

K_b for each level may be determined by previous data and simulated test.

Damage Level I ($K_b = 10$)

Cross pattern of breakage of concrete,

Spalling of surface layer.

Damage Level II ($K_b = 20$)

Partial failure of structure,

Concrete cracked into pieces, but most of them retained on steel reinforcement,

Some flying fragments.

Damage Level III ($K_b = 40$)

Complete failure of structure,

Most cracked pieces of concrete apart from steel reinforcement,

Many flying fragments.

(3) Correction Factor for Thick Wall Cylinder ($\delta \geqslant \frac{R}{10}$)

As equations (10) and (11) are suitable for thin wall cylinder, when used for thick wall cylinder, the charge value from equation (10) or (11) should be multiplied by K_1 to increase its value. K_1 is called correction factor for thick wall cylinder, as shown in Table 2.

Table 2 Correction Factor for Thick Wall Cylinder, K_1

δ/R	0.2	0.4	0.6	0.8	1.0
K_1	1.16	1.38	1.64	1.92	2.22

2. Concrete Structure of Rectangular Shape

A structure of rectangular cross section is shown in Figure 2.

The natural circular frequency for a rectangular structure is

$$\omega=\frac{0.23\delta c\Omega}{l^2} \tag{12}$$

where δ --- wall thickness of concrete structure, m;

c --- velocity of sound wave within concrete, m/sec;

L --- length of one side of rectangular, m;

Ω --- frequency factor, see Table 3.

Under uniform static pressure P_{eq}, the moment will be maximum at the corner of a rectangular structure, the stress at the corner will be

$$\sigma=\frac{6K_m P_{eq} l^2}{b\delta^2} \tag{13}$$

where K_m --- moment factor;

b --- width of section, use 1m;

Substitute equations (7) & (12) into equation (13), and also considering the correction factor for reinforcement K_s from equation (11a), then the equation for charge calculation of reinforced concrete rectangular structure will be

$$Q_{rec}=\left(\frac{K_b K_d R_t b}{0.0811\times K_m \Omega c}\right)^{1.59}\delta^{1.59}R^{1.41}, \tag{14}$$

where R --- perpendicular distance from inner surface of wall to charge center, m.

The value of K_m and Ω for various length ratio are shown in Table 3.

Table 3 Values of K_n and Ω for Rectangular Structure

B/L	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0
Ω	15.20	14.40	13.35	12.20	11.10	9.85	7.80	6.20	4.60	2.90	1.40
K_n	0.062	0.063	0.066	0.070	0.076	0.083	0.103	0.125	0.163	0.203	0.250
$K_n\Omega$	0.94	0.91	0.88	0.85	0.84	0.82	0.80	0.78	0.75	0.58	0.35

III. APPLICATION

Example 1

A trapezoidal hollow concrete block is shown in Fig 3, the volume of concrete is $1.02m^3$. This block is used in field experiment for mounting transducers for ground vibration measurement. The mark no. of concrete is 400. The wall thickness varies from 0.2--0.44m, take $\delta = 0.3m$ as mean value.

For blast demolition, the block is overturned with hollow bottom up and filled with water. The charge bag is hanged within water and covered with straw bags at top of block.

For simplification, the trapezoidal hollow space is treated as an equivalent rectangular, take B/L=0.7, from Table 3 we get:

$K_n = 0.066$, $\Omega = 13.35$,

From Table 1 we get

$K_d = 1.4$, $R_t = 24.5$ kg/cm^2, $c = 3670$ m/sec

for concrete of mark no. 400.

And from the arrangement of reinforcement we get $K_s = 2.0$.

Three blocks were demolished by underwater blast with different charges, $Q_1 = 0.15$kg, $Q_2 = 0.30$kg and $Q_3 = 0.80$kg.

Transform equation (14) into following form, and compute value K_b for charge Q_1, Q_2 and Q_3 respectively, then to predict

the degree of blast damage.

$$K_b = \frac{0.0811 \times K_n \cdot \Omega \cdot c}{K_d \cdot R_t \cdot b \cdot \delta}\left(\frac{Q}{K_s}\right)^{0.63} R^{-0.39}$$

The calculated K_b and underwater blast results are shown in Table 4.

Table 4 . Underwater Blast Results of Trapezoidal Concrete Hollow Block

Charge No.	Charge Wt.(kg)	Charge per Unit Volume	Calculated K_b	Blast Results
Q_1	0.15	0.147	14.5	Cracked to form large pieces, basicly the thick wall cracked at corners, and the thin wall broke into small pieces near around, no flying fragments
Q_2	0.30	0.294	22.5	Broke into five large pieces, part of steel reinforcement separated, many small pieces, flying fragments within 10m.
Q3	0.80	0.784	42.0	Total concrete blasted to small pieces, part of steel reinforcement separated, flying fragments within 50m, ready for clear up.

Example 2

A reinforced concrete chamber is shown in Fig. 4. The chamber is used in field experiment as a measurement station.

The thickness of four side walls is 0.15m, and the thickness of top slab is 0.10m. The inner dimension is 4.0m in length, 2.0m in width and 1.8m in height. Mark no. of concrete is 200, with ϕ 12@180 mesh and ϕ 8@180 mesh steel reinforcement, one layer each respectively.

The charge wt. is calculated from equation (14).

As the blast was taken at spacious area, and there are no problems about safety distances, therefore we chose the factor of damage degree $K_b=30$.

From Table 1, for concrete mark no. 200, $K_d=1.4$, $R_t=13$ kg/cm^2, c=2362m/sec, $\delta=0.15$m.

For uniformity of wall damage, two charge bags are designed. The distance between bags is 2m, distance to end walls are 1m. As the front wall has wing wall extended on each end, the charge bag is a little nearer to the front wall, the distance is 0.95m, and the distance from bag to the rear wall is 1.05m. The average distance R=1.0m is used in calculation. As there are two charge bags, the chamber may be considered as two squares, thus B/L=1.0. From Table 3, we have $K_H=0.083$, $\Omega=9.85$.

For steel of mark no. 3, $K_{ds}=1.35$ and $R_s=3800$kg/cm^2. The total steel area per unit length of concrete is $\Sigma A_s=9.05$ cm^2.

From equation (11a), we get $K_s=2.71$.

The calculated charge wt. for each bag will be

$$Q=K_s\left(\frac{K_b K_d R_t b}{0.0811 K_n \Omega c}\right)^{1.59}\delta^{1.59}R^{1.41}$$

$$=2.71\left(\frac{30\times1.4\times13\times1}{0.0811\times0.083\times9.85\times3260}\right)^{1.59}\times(0.15)^{1.59}\times(1.0)^{1.41}$$

$$=0.58 \text{ kg}$$

In practice, the charge bags are made of powder TNT, the actual wt. for each bag is 0.65kg. The bag are 0.6m above bottom slab. The water height is about 1.5m.

After blast, the concrete break into pieces, most pieces are still hanging on the reinforcement steel mesh, with some flying fragments within 30m range. This result fulfills the blast requirement. The wing walls which have no contact with water are basicly no damage, and as the wing walls attribute some stiffening to the front wall, the damage of front wall is somewhat lighter than other walls.

As the distance from charge bag to rear wall is 11% larger than that to front wall, the top slab of chamber is turned to the rear, and water flushed out from the opening between the top slab and front wall.

The result of blast is shown in Fig.5

CONCLUSION

The equations presented in this paper give satisfactory results in practice of blast demolition.

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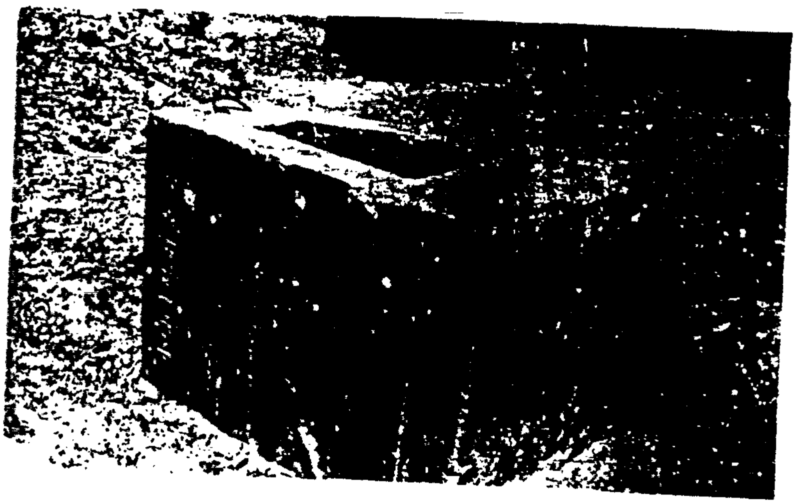

Fig.3

Fig.5